A preliminary survey of species diversity of the freshwater insects in Inner Mongolia

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Abstract: 【Aim】This study aims to provide the basic scientific data of aquatic insect species in Inner Mongolia and a solid base for their potential application in freshwater quality monitoring and protection by the government and scientists in the future. 【Methods】Benthic aquatic insects were sampled by using a qualitative collection method and the water quality was assessed by the family biotic index (*FBI*), EPT species richness and Shannon-Wiener biodiversity index. 【Results】Of 187 freshwater insect species in 72 genera, 59 families, 7 orders collected in the 52 localities, 1 species was new to science; 2 families, 3 genera and 25 species were newly recorded in Inner Mongolia; 1 genus and 2 species were recorded for the first time in China; and 56 additional species are under identification. The diversity of Trichoptera and Ephemeroptera were the highest while that of Plecoptera was the lowest in recorded 7 orders; the proportions of families and individuals of the two orders accounted for 42.37% and 84.29%, respectively, so Trichoptera and Ephemeroptera are dominant groups among the seven orders. The localities of rich species diversity were distributed mainly in the eastern Inner Mongolia, including Hulunber, Hinggan League, Tongliao and Chifeng. The water quality ranks assessed by the family biotic index, EPT species richness and Shannon-Wiener biodiversity index showed that the evaluation results of *FBI* and EPT species richness were similar, but differed greatly from that of Shannon-Wiener biodiversity index. 【Conclusion】There are more abundant species of Trichoptera and Ephemeroptera with lower tolerance value in Inner Mongolia, so the caddisflies and mayflies are more suitable and better candidates as indicators of water quality in this region.

Key words: Trichoptera; Plecoptera; Ephemeroptera; water quality; freshwater; species diversity

1 INTRODUCTION

As we all know, insects are the dominant group of animals on earth today, and more than one million species have been described, of which about 100 000 insects (belonging to 13 orders) live in the water or with water during at least one life history stage, and they are collectively referred as aquatic insects (Huang and Cai, 2006). They occupy a variety of fresh waters (Ke *et al.*, 1996), and account for more than 95% of benthic macroinvertebrates (Xu, 2001), and can make quick response to the pollution source (Morse *et al.*, 1994), thus any changes in their composition and community structure mark changes in water quality. Moreover, groups of aquatic insects have different tolerance to the water pollutants (Morse *et al.*, 1994). Therefore, aquatic insects are widely used for biomonitoring water quality, especially the taxa with high sensitivity to water pollution, taxa with high sensitivity to water pollution, such as Ephemeroptera, Trichoptera and Plecoptera; other groups, such as Coleoptera, Hemiptera, Diptera, Lepidoptera, Odonata, Megaloptera, Neuroptera, and Collembola, are also used to assess the water quality (Tong *et al.*, 1995).

Aquatic insects are common subjects of ecological research and environmental monitoring and assessment (Suter and Cormier, 2015). The value of aquatic insects for monitoring water quality was found in Greece and Germany in the 18th century (Kolkwitz and Marsson, 1909). The measures of the community diversity were proposed to overcome the problems of indicator organisms

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during the late 1940s through the 1960s (Shannon, 1948; Simpson, 1949; Menhinick, 1964). The "biotic indices" were developed to estimate the tolerance of each family or each species to pollution, and their tolerance values were then being generated (Hilsenhoff, 1977, 1988) during the 1970s and 1980s. It has been found that larvae of a mayfly and a stonefly were more tolerant to heavy metals than most fish when they were exposed to lead, zinc, copper and silver, and aquatic insects may serve as effective biological monitors of heavy metal pollution where fish-kills are involved (Nehring, 1976). In 1989, the United States Environmental Protection Agency established protocols for "rapid bio-assessment" of streams and rivers using insects and fish (Plafkin *et al*., 1989). Since then, scientists turned to use multiple biological indices to assess water quality. The family-level tolerant values are the evidence of assessment of water quality (Bode *et al*., 1996; Hauer and Lamberti, 1996). Based on the benthic animals, Karr and Chu (2000) firstly proposed index B-IBI and its evaluation criteria for water quality assessment. Aagaard *et al*. (2004) took samples of larvae and adults each year from 1987 to 2002 at three to five localities in River Atna, Norway, and a total of 16 taxa of Ephemeroptera, 24 taxa of Plecoptera, 39 taxa of Trichoptera, 125 taxa of Chironomidae and 52 taxa of Limoniidae from Diptera were identified. And the results of the long-term sampling in Atna were discussed in relation to the practicalities and the cost-benefit of zoobenthos in efficient biomonitoring in rivers. Bonada *et al*. (2006) applied 12 criteria to 9 recent approaches that ranged from the sub-organismal to the ecosystem level, and the results showed that no recent approach met all the 12 criteria, so they suggested that the societies and governments prioritized how these criteria should be ranked if the use of biomonitoring information with important financial consequences was given. Mora (2011) characterized the population of aquatic insects and the water quality according to the natural and human alterations present in the study site, measured some environmental variables, and analyzed the relationship between these environmental variables and aquatic insects. Wongsanoon *et al*. (2011) investigated the aquatic insect diversity and calculated some biotic indices, such as Shannon-Wiener index, Thai biological monitoring working party score, average score per taxon, Ephemeroptera, Plecoptera and Trichoptera index, EPT proportion and proportion of Diptera, to evaluate water quality in Klong Pae, Southern Thailand between September 2008 and June 2009, and compared the differences of the evaluations by using aquatic insects and by using entire macroinvertebrate groups. Rochlin *et al*. (2011) conducted the first taxonomic survey of salt marsh aquatic insects on Long Island, USA and evaluated their utility for non-target pesticide impacts and environmental biomonitoring by collecting a total of 18 species from 11 families and 5 orders during the 5-month study period, and found that 9 species from 7 families were the most suitable candidates for salt marsh health assessment. Apart from pollutants in water, Harun *et al*. (2015) found that suspended sediment and the precipitation anomalies resulted in low abundance of aquatic insects and seasonal variations of water quality.

Maltchik *et al*. (2012) analyzed the distribution pattern of 82 genera from 4 aquatic insect orders (*i*. *e*., Diptera, Odonata, Ephemeroptera and Trichoptera) in Southern Brazil wetlands, and found that 32 biogeographic nodes corresponded to 4 priority areas for conservation of the aquatic insect diversity, so the 4 priority areas pointed by node cluster criterion must be considered in further inclusions of areas for biodiversity conservation in Southern Brazil wetlands. Conti *et al*. (2014) used a dataset of bioecological traits of 1942 Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa and a fuzzy correspondence analysis (FCA) with longitudinal and biogeographical gradients to analyze the potential vulnerability of EPT species to climate change and the geographical occurrence patterns of these potentially endangered species at the scale of European ecoregions, the result showed that aquatic insects of southern European ecoregions emerged as those most endangered in terms of potential vulnerability to climate change. Moreover, the comparative multi-taxon studies could be the first step toward developing integrative monitoring or assessment tools by means of non-arbitrary statistical methods. Shayeghi *et al*. (2015) conducted survey of aquatic insects in Iran, and considered that understanding the fauna of aquatic insects will provide a clue for possible biological control of medically important aquatic insects such as *Anopheles* as the malaria vectors. Similar studies are carried out in India (Takhelmayum and Gupta, 2015). Moreover, Mongolian Aquatic Insect Survey (MAIS) during 2002 – 2011 is as a multi-national collaborative project among Mongolian, American and European scientists, using the collected data to understand the impacts on its aquatic ecosystems (Gelhaus *et al*.,

2011). The governments of many states in America support "the Water Quality Branch" to monitor and assess the water quality in the state's streams, lakes and wetlands such as Kentucky, Oregon, Michigan and Florida (see "USGS Water-Quality Information Pages" at https://water.usgs.gov/owq/).

In China, studies on aquatic insects started from the 1920s (Yang and Tian, 1994), mainly focusing on taxonomy, rather than on ecological aspects. Until early 1980s, benthic macroinvertebrates such as Chironomidae were applied to assess the water pollution (Liu *et al*., 1981). As the application increased (Yang and Hu, 1986; Yang *et al*., 1992), many other diversity indices were proposed to assess and monitor water quality in the past twenty years. Tong *et al*. (1995) assessed the water quality of the streams in Guangdong Province by using Shannon-Wiener diversity index, EPT taxa richness, biotic index and family-level biotic index. Ke *et al*. (1996) evaluated the water quality of Fengxi River, Anhui Province, and discussed the applicability of Shannon-Wiener diversity, EPT richness, biotic index and family biotic index, and highly recommended biotic index (*BI*) and family biotic index (*FBI*) bioassessment methods in China. Similar studies were conducted by Wang *et al*. (1999) in Mt. Lushan Nature Reserve, Jiangxi, Zhou (2002) in Liaoning, Wang (2003) in Zhejiang, Zhang *et al*. (2006) and Cai *et al*. (2014) in Jiangsu, Li *et al*. (2007) in Heilongjiang, He *et al*. (2012) in Yunnan, Wang (2015) in Xinjiang, Wang *et al*. (2016) in Hunan, Cao *et al*. (2017) in the Beijiang river in both Jiangxi and Guangdong, and Li *et al*. (2017) in Pearl River Delta. Among these studies, Shannon-Wiener biodiversity index and biotic index are the most commonly used index. For this reason, we adopted them mainly to evaluate water quality in Inner Mongolia.

The Inner Mongolia Autonomous Region is situated in northernmost area of China, bordering Russia and Mongolia on the north and adjacent to Gansu province on the west, to Ningxia, Shaanxi, Shanxi, Hebei provinces on the south, and to Liaoning, Jilin and Heilongjiang provinces on the east. Though it is the third largest province of China, the water surface area of rivers, lakes and reservoirs only account for 0.8% of the whole land area. Most of the area is plateau with average elevation 1 000 m or so. There are five vegetation types from west to east (*i*. *e*. desert, desert grassland, typical grassland, forest steppe and forest). Of a total of 184 natural reserves in Inner Mongolia reported by the Ministry of Environmental Protection of the People's Republic of China, only 45 are related to the freshwater resources and most of them are still in conditions of traditional culture. Before this study, only Nengnaizhabu (1999) recorded 130 species of aquatic insects belonging to 34 families, 12 orders, but only 7 species of Ephemeroptera, 3 species of Plecoptera and 4 species of Trichoptera, a complete biodiversity survey of the freshwater insects is needed in Inner Mongolia, especially the one regarding the conservation of the fresh water resource.

On the other hand, the limited freshwater resources and the freshwater insects are threatened by the flourishing and prosperous tourism industry in Inner Mongolia, so there is an urgent need to understand and protect the aquatic insect's fauna in the province. In 2014 – 2015, we carried out a project aiming to provide the scientific data for the purpose above-mentioned and to build a long-term conservation and monitoring system for the government and scientists in the future. This two-year sampling research is focusing on the following aspects: (1) New species or new records of the freshwater insects; (2) A checklist of all known freshwater insects and an emphasis on the indicator species for monitoring the water quality; (3) Understanding what the good habitats of those indicators are, how the population dynamics is and what the influence of the human activity is. The results will provide the scientific data for making a precaution of freshwater quality and biodiversity, building a long-term conservation and monitoring system for the government and scientists, enhancing the local people to understand the importance of freshwater resource and biodiversity and participate actively in conserving the diversity of aquatic insects of Inner Mongolia. Fifty-two localities were surveyed in this project, and a total of 187 aquatic species were collected. The results could be treated as the first revision to aquatic insects of the book "Insects of Inner Mongolia" published in 1999.

2 MATERIALS AND METHODS

2.1 Sampled sites

Fifty-two collection localities are situated in Hulunber, Hinggan League, Tongliao, Chifeng, Xilinguole League, Baotou City, and Alxa Left Banner. These 52 localities belong to four major drainages. Localities 1 – 4 belong to Gen River branch of Argun River of the source of Heilonjiang River, which gathers with Onon River in the estuary

of Gen River and is a boundary river of China and Russia; localities 5 – 11 belong to Halha River branch of Argun River; locality 12 belongs to the Taoer River branch of the crossing of the Songhua River and Nenjiang River; localities 13 – 37 belong to the Xar Moron River branch and Laoha River branch of the Liao River originated from Hebei Province; localities 38 – 52 belong to the branches of the Yellow River running across many crop fields, deserts and other dry lands. The geographic coordinate data and elevations of these localities are presented in Table 1.

Table 1 Sampling localities of this survey in Inner Mongolia

No.	Locality	Latitude (°N)	Longitude (°E)	Altitude (m)
1	Fishing pond, Hanma National Reserve, Hulunber	51°19′50.64″	121°29′46.41″	805
2	Central station, Hanma National Reserve, Hulunber	51°26′40.75″	122°30′52.95″	831
3	Monitoring station, Hanma National Reserve, Hulunber	51°26′21.78″	122°29′13.84″	823
4	Bonuo River, Hanma National Reserve, Hulunber	51°27′34.37″	122°33′20.34″	860
5	Hui River, Hulunber	48°56′10.30″	119°40′36.94″	631
6	Microlithic site, Hui River, Hulunber	49°00′46.24″	119°43′05.02″	615
7	Dike of Hui River, Hulunber	48°55′31.93″	119°40′15.83″	631
8	Sanchakou area, Urson River, Hulunber	48°21′27.24″	117°34′33.71″	542
9	Budong River, Arxan city, Hinggan League	47°17′26.49″	120°24′37.97″	1 107
10	Wuliquan, Arxan city, Hinggan League	47°11′43.65″	119°55′55.64″	967
11	Upstream regions of Halaha River, Arxan city, Hinggan League	47°17′58.72″	120°21′53.67″	1 050
12	Taoer River, Bailang Town, Hinggan League	47°06′30.32″	120°05′08.92″	1 192
13	Source of Xiaoqing River, Daqinggou, Tongliao	42°48′32.56″	122°12′60.00″	238
14	Central area of Xiaoqing River, Daqinggou, Tongliao	42°46′05.95″	122°15′12.42″	210
15	The source of Daqinggou River, Tongliao	42°48′45.52″	122°09′49.95″	235
16	Central area, Daqinggou River, Tongliao	42°44′59.68″	122°12′33.03″	169
17	Bridge of Xiaoqing Lake, Daqinggou, Tongliao	42°45′01.66″	122°12′39.37″	176
18	Bottom of Daqinggou, Tongliao	42°47′54.33″	122°10′17.28″	213
19	Sanchakou, Daqinggou, Tongliao	42°43′41.45″	122°11′59.86″	171
20	Stone bridge, Dalinor Lake, Chifeng	43°18′11.40″	116°50′16.82″	1 216
21	Zhagasitai Lake, Ar Horqin Banner, Chifeng	43°54′35.94″	120°31′43.07″	280
22	Haiqing Dike, Saihanwula National Reserve, Chifeng	44°17′59.76″	118°16′08.94″	1 289
23	Ecological Station, Saihanwula National Reserve, Chifeng	44°14′38.56″	118°40′02.50″	1 192
24	Zhenggou, Saihanwula National Reserve, Chifeng	44°11′41.60″	118°38′23.80″	1 088
25	Forestry station, Wangyedian, Harqin Banner, Chifeng	41°38′53.99″	118°21′22.01″	992
26	Dahushi Reservoir, Wangyedian, Harqin Banner, Chifeng	41°23′15.35″	118°36′20.08″	722
27	Liudaogou, Wangyedian, Harqin Banner, Chifeng	41°37′10.97″	118°19′28.17″	1 023
28	Binlanggou, Wangyedian, Harqin Banner, Chifeng	41°36′34.62″	118°26′11.81″	1 223
29	Upstream regions of Xiaogoupan, Wangyedian, Harqin Banner, Chifeng	41°43′42.64″	118°08′03.31″	1 287
30	Maojing Dike, Wangyedian, Harqin Banner, Chifeng	41°28′46″	118°06′05″	1 020
31	North Ditch of Dadian, Wangyedian, Harqin Banner, Chifeng	41°39′29.46″	118°12′23.02″	1 288
32	Toudao Ditch, Wangyedian, Harqin Banner, Chifeng	41°35′52.18″	118°14′02.31″	1 210
33	Meilin River, Duanmu Ditch, Wangyedian, Harqin Banner, Chifeng	41°40′05.68″	118°19′26.03″	1 006
34	Bayannur Lake, Hunshandake Sandy Land, Xilinguole League	43°01′27.44″	115°49′12.62″	1 253
35	Chachaer River, Hunshandake Sandy Land, Xilinguole League	43°06′15.07″	115°42′22.38″	1 220
36	Gaogesutai River, Hunshandake Sandy Land, Xilinguole League	43°00′54.59″	115°45′38.38″	1 238
37	Tele River, Hunshandake Sandy Land, Xilinguole League	43°00′11.63″	115°47′09.14″	1 229
38	Nanhai wetland Park, Baotou City	40°32′13.33″	110°00′08.65″	1 013
39	Kekao Station, Halawugou, Helan Mountain, Alxa Left Banner	38°51′58.65″	105°54′50.17″	1 962
40	Goukou, Beigou, Helan Mountain, Alxa Left Banner	38°51′57.38″	105°53′31.50″	2 370
41	Shangbinqing, Shuimogou, Helan Mountain, Alxa Left Banner	38°56′12.76″	105°53′47.39″	2 065
42	Huoshaopo, Shuimogou, Helan Mountain, Alxa Left Banner	38°56′35.35″	105°53′13.07″	1 910
43	Langdongzi, Shuimogou, Helan Mountain, Alxa Left Banner	38°55′58.52″	105°55′16.69″	2 124
44	Hougou, Shuimogou, Helan Mountain, Alxa Left Banner	38°56′06.54″	105°57′03.94″	2 330
45	Chagou, Shuimogou, Helan Mountain, Alxa Left Banner	38°56′07.03″	105°55′32.30″	2 143
46	Zhuanwanchu, Shuimogou, Helan Mountain, Alxa Left Banner	38°56′08.68″	105°53′57.55″	2 047
47	Goukou (light trap), Shuimogou, Helan Mountain, Alxa Left Banner	38°57′01.66″	105°52′48.40″	1 954
48	Taerling Reservoir, Helan Mountain, Alxa Left Banner	39°02′57.28″	105°56′00.56″	1 704
49	Goukou, Luanchaigou, Helan Mountain, Alxa Left Banner	39°01′56.41″	106°00′56.05″	2 115
50	Badan Lake, Badanjilin Desert, Alxa Right Banner	39°33′07.72″	102°21′51.38″	1 281
51	Xiaoguanjing Wetland, Shajin, Alxa Left Banner	40°39′15.81″	106°38′28.69″	1 026
52	North Bank, Nalin Lake, Alxa Left Banner	40°31′50.17″	106°39′08.98″	1 037

2.2 Sampling method

Benthic aquatic insects were sampled by a qualitative collection method (Chutter, 1972; Lenat *et al.*, 1980; Hilsenhoff, 1988; Plafkin, 1989; Morse *et al.*, 1994; Tong, 1995), that is, using aquatic insects collecting nets and two-piece heavy duty D-frame aquatic nets (the above nets are supported by BIOQUIP products and domestic products with length 1 m and 5 m, respectively) to collect 30 nets during 30 meter span along the bank of the river or lake in every locality and sweeping the adults on the plants along the river or lake. All insects were deposited in the 75% ethanol for observation and identification in the laboratory.

2.3 Biodiversity indices

The most commonly used diversity indices were adopted and calculated as follows. The software version 11.0 of DPS analysis (Tang and Zhang, 2013) was run in this study.

(1) Shannon-Wiener biodiversity index:

$$H' = -\sum_{i=1}^{s} P_i \ln(p_i).$$

P_i is the proportion of the total samples of community species represented by the ith species, and s is the species number of community.

(2) Simpson index:

$$D = 1 - \sum_{i=1}^{s} P_i^z.$$

P_i is the proportion of the total samples of community species represented by the ith species, and s is the species number of community.

(3) Evenness (Pielou index):

$$J' = H'/\ln S.$$

H' is the Shannon-Wiener diversity index, and S is the species richness.

(4) Family biotic index (Mandaville, 2002):

$$FBI = \sum \frac{x_i t_i}{n}.$$

x_i is the number of individuals in the ith taxon, t_i is the tolerance value of the ith taxon, and n is the total number of organisms in the sample.

2.4 Assessment method of water quality

Shannon-Wiener biodiversity index, EPT species richness and family biotic index were used for biological assessment of water quality in this paper. The evaluation criteria are as follows.

(1) Shannon-Wiener biodiversity index (H') (Lloyd and Ghelardi, 1964):

Evaluation criterion: $H' > 3$ stands for "Clean", $3 < H' > 1$ stands for "slight pollution", and $H' < 1$ stands for "serious pollution".

(2) EPT species richness (Lenat *et al.*, 1980):

Evaluation criterion: $S > 41$ stands for "very clean", $41 < S > 32$ stands for "clean", $31 < S > 16$ stands for "fairly clean", and $S < 16$ stands for "general".

(3) Family biotic index (Hilsenhoff, 1988):

Evaluation criterion: $3.75 < FBI > 0.00$ stands for "super clean", $4.25 < FBI > 3.76$ stands for "very clean", and $5.00 < FBI > 4.26$ stands for "clean".

3 RESULTS

3.1 Diversity and characteristics of aquatic insects in Inner Mongolia

A checklist of species, genus and family of the aquatic insects is listed in Table 2.

Table 2 A checklist of aquatic insects from the field survey

Order	Family	Genus and species
Plecoptera	* Chloroperlidae	* *Alloperla mediata*, * *Utaperla orientalis*, * *Suwallia decolorata*, * *Suwallia teleckojensis*, * *Suwallia talalajensis* (Li *et al.*, 2015a, 2015b)
	Nemouridae	*Amphinemura didyma*, * *Amphinemura hasta*, *Nemoura geei*, * *Nemoura papilla*; *Amphinemura* sp1, sp2, sp3; *Nemoura* sp1, sp2, sp3, sp4, sp5, sp6, sp7
	Perlodidae	* *Isoperla eximia*, Arcynopterygini sp., Perlodini sp.
	Capniidae	# *Mesocapnia altaica*, # *Mesocapnia silvatica*, *Mesocapnia* sp.
Trichoptera	Apataniidae	*Apataniana spinosa*, *Apatania* sp., *Apataniana* sp.
	Brachycentridae	*Brachycentrus* sp.
	Glossosomatidae	*Glossosoma* sp.
	Goeridae	*Goera* sp.
	Hydropsychidae	*Cheumatopsyche infascia*, *Hydropsyche botosaneanui*, *Hydropsyche kozhantschikovi*, *Hydropsyche* sp1, sp2
	Hydroptilidae	*Hydroptila* sp.
	Lepidostomatidae	* *Lepidostoma elongatum*, *Lepidostoma* sp.
	Leptoceridae	*Oecetis nigropunctata*, *Setodes argentata*, *Parasetodes* sp., *Setodes* sp.
	Limnephilidae	*Dicosmoecus jozankeanus*, * *Ecclisomyia kamtshatica*, *Hydatophylax soldatovi*, *Limnophilus correptus*, *Dicosmoecus* sp., *Grammotaulius* sp., *Limnephilus* sp.
	Molannidae	*Molannodes* sp.

Table 2 continued

Order	Family	Genus and species
Trichoptera	Philopotamidae	*Dolophilodes bilobata*
	Phryganeidae	*Semblis phalaenoides*, *Semblis* sp.
	Polycentropodidae	* *Agripnia pagetana*, * *Agrypnia picta*, *Plectrocnemia* sp.
	Rhyacophilidae	** *Rhyacophila shiliae* (Sun, 2016), *Himalopsyche* sp.
	Stenopsychidae	*Stenopsyche* sp.
Ephemeroptera	* Baetidae	* *Alainites muticus*, *Baetiella tuberculata*, * *Baetis alpinus*, * *Baetis fuscatus*, * *Cloeon incriptum*, *Cloeon dipterum*, * *Cloeon simile*, *Labiobaetis atrebatinus*, * *Procloeon pennulatum*, *Acentrella* sp., *Alainites* sp., *Baetis* sp1, sp2, sp3
	Siphlonuridae	*Siphlonurus immanis*, *Siphlonurus lacustris*
	Metretopodidae	* *Metretopus alter*
	Heptageniidae	* *Cinygmula autumnalis*, *Epeorus pellucidus*, *Ecdyonurus scalaris*, *Heptagenia lutea*, *Cinygmula* sp1, *Epeorus* sp1
	Leptophlebiidae	*Choroterpes altioculus*, * *Paraleptophlebia chocorata*, *Paraleptophlebia strandii*
	Ephemerellidae	*Drunella triacantha*, *Ephemerella atagosana*, *Ephemerella aurivilli*, *Ephemerella ignita*, * *Ephemerella nuda*, *Ephemerella setigera*, * *Serratella zapekinae*, *Uracanthella rufa*
	Caenidae	* *Caenis luctuoso*, *Caenis rivulorum*, * *Caenis strugaensis*
	Ephemeridae	*Ephemera sachalinensis*
	Neoephemeridae	*Neoleptophlebia chocolata*
	Ameletidae	*Ameletus cedrensis*, *Ameletus inopinatus*, *Ameletus montanus*
Coleoptera	Helophoridae	*Helophorus* sp1, sp2, sp3
	Hydrophilidae	*Berosus fulvus*, *Enochrus bicolor*, *Enochrus fuscipennis*, * *Enochrus melanocephalus*, *Enochrus quadripunctatus*, *Enochrus simulans*, *Hydrocassis mongolica*, *Paracymus relaxus*, *Berosus* sp., *Helochares* sp., *Laccobius colon*, *Laccobius* sp.
	Haliplidae	*Haliplus basinotatus*, *Haliplus similis*, *Haliplus* sp.
	Noteridae	*Noterus japonicus*
	Dytiscidae	*Agabus amoenus*, *Agabus brandti*, * *Agabus thomsoni*, *Agabus udege*, *Cybister chinensis*, *Graphoderus adamsi*, # *Graphoderus austriacus*, *Graphoderus bieneri*, *Graphoderus elatus*, *Hydaticus grammicus*, *Hydroglyphus japonicus*, *Hygrotus inaequalis*, *Ilybius anjae*, *Ilybius apicalis*, *Laccophilus difficilis*, *Nebrioporus airumlus*, *Oreodytes dauricus*, *Platambus ussuriensis*, *Rhantus suturalis*, *Agabus* sp., *Hydroglyphus* sp., *Hygrotus* sp1, sp2, *Ilybius* sp.
	Hydraenidae	*Ochthebius* sp.
Hemiptera	Corixidae	*Callicorixa praeusta praeusta*, *Callicorixa wollastoni*, *Cymatia bonsdorffii*, *Cymatia coleoptrata*, *Paracorixa concinna amurensis*, *Paracorixa wui*, *Sigara assimilis*, *Sigara distincta*, *Sigara fallen*, *Sigara weymarni*
	Nepidae	*Nepa cinerea*, *Nepa hoffmanni*, *Ranatra falloui*
	Notonectidae	*Notonecta amplifica*, *Notonecta glauca glauca*, *Notonecta kiangsis*, # *Notonecta nigra*
	Naucoridae	*Ilyocoris cimicoides cimicoides*
	Belostomatidae	*Appasus major*
	Micronectidae	*Micronecta sahlbergii*
Odonata Anisoptera	Aeshnidae	*Aeshna crenata*, *Aeschnophlebia longistigma*, *Anax parthenope julius*, *Aeshna* sp.
	Gomphidae	*Ophiogomphus* sp.
	Corduliidae	*Epitheca bimaculata*, *Somatochlora graeseri*
	Libellulidae	*Crocothemis servilia*, *Sympetrum eroticum eroticum*, *Sympetrum flaveolum*, *Sympetrum parvulum*, *Sympetrum pedemontanum*, *Sympetrum* sp1
Odonata Zygoptera	Calopterygidae	*Atrocalopteryx atrata*
	Lestidae	*Lestes barbarous*, *Sympecma paedisca*
	Coenagrionidae	*Enallagma cyathigerum*, *Ischnura asiatica*, *Ischnura elegans*, *Paracercion hieroglyphicum*
Diptera	Canacidae spp., Ceratopogonidae spp., Chaoboridae spp., Chironomidae spp., Culicidae spp., Dixidae spp., Simulidae spp., Ephydridae spp., Tabanidae spp., Tipulidae spp.	

* New records of genera and species to Inner Mongolia; ** Species new to science; # New records of genera and species to China.

A total of 16 645 individuals were collected and examined, 187 species were identified (the number of species of Diptera is not counted in, and only the numbers of its families and individuals are calculated), they belong to 72 genera, 59 families, 7 orders (Table 2). Among them, 2 families, 3 genera and 25 species are newly recorded in Inner Mongolia, 1 genus and 2 species are newly recorded

in China, 1 species is new to science, and 56 species are under identification including a species new to Science.

Trichoptera and Ephemeroptera are at the top (Table 3). The proportions of families and individuals of two orders accounts for 42.37% and 84.29%, respectively, so the two orders are dominant groups among the seven orders, and highly available for monitoring water quality. But the species diversity of Plecoptera is lower distinctively and is not suitable for monitoring water quality due to lower numbers of the species and individuals in Inner Mongolia.

Table 4 shows that, of the 15 Trichoptera families in 34 localities, the most common family is Limnephilidae, having been collected widely from 24 localities; closely followed by Apataniidae and Hydropsychidae, both from 11 localities; other 8 families were found in less than 10 localities (Rhyacophilidae 7, Lepidostomatidae 6, Phryganeidae 5, Glossosomatidae 4, Brachycentridae 3, Hydroptilidae 2, Leptoceridae 2, and Molannidae 2); and Goeridae, Philopotamidae, Polycentropodidae and Stenopsychidae was found only in one locality.

Table 3 Proportions of families and individual samples in seven aquatic insect orders

Order	Family		Individuals	
	Number	Proportion (%)	Number	Proportion (%)
Plecoptera	4	6.78	826	4.96
Trichoptera	15	25.42	8 038	48.29
Ephemeroptera	10	16.95	5 992	36.00
Coleoptera	7	11.86	253	1.52
Hemiptera	6	10.17	283	1.70
Odonata	7	11.86	228	1.37
Diptera	10	16.95	1 025	6.16
Total	59		16 645	

Table 4 Numbers of families, species and individuals of the 52 localities of this survey

Administrative area	Locality no.	Family name	Family number	Species number	Individual number
Hulunber	1	Limnephilidae, Siphlonuridae, Ephemerellidae, Chironomidae	4	5	56
	2	Apataniidae, Limnephilidae, Rhyacophilidae, Ameletidae, Leptophlebiidae, Ephemerellidae, Siphlonuridae, Tipulidae, Chironomidae	9	11	315
	3	Apataniidae, Limnephilidae, Glossosomatidae, Rhyacophilidae, Heptageniidae, Ameletidae, Siphlonuridae, Baetidae, Leptophlebiidae, Ephemerellidae, Metretopodidae, Dytiscidae, Gyrinidae, Tipulidae	14	23	498
	4	Limnephilidae, Rhyacophilidae, Ameletidae, Baetidae, Caenidae, Heptageniidae, Ephemerellidae, Leptophlebiidae, Tipulidae	9	12	859
	5	Perlodidae, Hydropsychidae, Polycentropodidae, Rhyacophilidae, Leptoceridae, Ameletidae, Caenidae, Heptageniidae, Baetidae, Ephemerellidae, Leptophlebiidae, Siphlonuridae, Gyrinidae, Dytiscidae, Chironomidae	15	36	403
	6	Corixidae	1	1	23
	7	Corixidae, Molannidae	2	2	4
	8	Molannidae, Caenidae, Baetidae, Chironomidae	4	8	28
Hinggan League	9	Nemouridae, Perlodidae, Chloroperidae, Limnephilidae, Lepidostomatidae, Stenopsychidae, Ameletidae, Baetidae, Metretopodidae, Heptageniidae, Ephemerellidae, Neoephemeridae, Leptophlebiidae, Siphlonuridae, Dytiscidae	15	30	2 477
	10	Apataniidae	1	2	3
	11	Nemouridae, Perlodidae, Chloroperidae, Limnephilidae, Ameletidae, Baetidae, Ephemerellidae, Heptageniidae, Metretopodidae, Neoephemeridae, Siphlonuridae, Chironomidae	12	15	1 251
	12	Nemouridae, Perlodidae, Capniidae, Chloroperidae, Apataniidae, Glossosomatidae, Lepidostomatidae, Limnephilidae, Rhyacophilidae, Heptageniidae, Ephemerellidae, Neoephemeridae, Ameletidae, Siphlonuridae, Baetidae, Leptophlebiidae, Ephemerellidae, Dytiscidae, Chironomidae	19	30	991
Tongliao	13	Baetidae, Dytiscidae, Ephydridae	3	16	458
	14	Nemouridae, Hydropsychidae, Dytiscidae, Ephydridae	4	17	224
	15	Nemouridae, Phryganeidae, Limnephilidae	3	3	101
	16	Brachycentridae, Hydropsychidae, Lepidostomatidae, Limnephilidae, Baetidae	5	5	321
	17	Brachycentridae, Hydropsychidae, Limnephilidae, Phryganeidae, Baetidae, Heptageniidae	6	6	77
	18	Nemouridae, Limnephilidae, Brachycentridae	3	3	1 106
	19	Nemouridae, Baetidae, Ephemerellidae, Heptageniidae, Dytiscidae	5	16	46

Table 4 continued

Administrative area	Locality no.	Family name	Family number	Species number	Individual number
Chifeng	20	Caenidae, Baetidae, Chironomidae	3	5	27
	21	Micronectidae	1	1	56
	22	Choloroperidae	1	1	1
	23	Apataniidae, Limnephilidae, Baetidae, Dytiscidae, Gyrinidae, Chironomidae	6	9	37
	24	Apataniidae, Limnephilidae, Baetidae, Dytiscidae, Gyrinidae, Chironomidae	4	5	158
	25	Ephemeridae	1	1	1
	26	Baetidae, Tabanidae	2	3	52
	27	Nemouridae, Hydropsychidae, Baetidae, Ephemeridae, Tabanidae, Chironomidae	6	11	301
	28	Nemouridae, Apataniidae, Limnephilidae, Rhyacophilidae, Baetidae, Heptageniidae, Ephemerellidae, Simulidae	8	13	862
	29	Limnephilidae, Phryganeidae, Heptageniidae, Baetidae, Caenidae, Ephemerellidae	6	11	578
	30	Apataniidae, Limnephilidae, Limnephilidae, Rhyacophilidae, Phryganeidae, Heptageniidae, Baetidae, Dytiscidae, Chironomidae, Tabanidae	10	9	832
	31	Limnephilidae, Phryganeidae, Heptageniidae, Baetidae, Ephemerellidae, Chironomidae	6	7	366
	32	Limnephilidae, Heptageniidae	2	2	48
	33	Goeridae, Hydropsychidae, Hydroptilidae, Baetidae, Ephemerellidae, Dytiscidae, Chironomidae, Tabanidae	8	15	541
Xilinguole League	34	Leptoceridae, Caenidae, Chironomidae	3	5	35
	35	Limnephilidae, Baetidae, Ephydridae	3	7	22
	36	Limnephilidae	1	1	4
	37	Haliplidae, Dytiscidae, Hydrophilidae, Noteridae	4	4	14
Baotou	38	Hydrophilidae	1	1	1
Alxa left banner	39	Nemouridae, Perlodidae, Limnephilidae, Hydroptilidae, Gyrinidae, Dytiscidae, Chironomidae	7	20	334
	40	Heptageniidae, Dytiscidae, Simulidae, Chironomidae	4	5	59
	41	Nemouridae, Apataniidae, Hydropsychidae, Lepidostomatidae, Dytiscidae, Tabanidae, Chironomidae	7	10	256
	42	Nemouridae, Apataniidae, Philopotamidae, Glossosomatidae, Hydropsychidae, Limnephilidae, Baetidae, Dytiscidae, Chironomidae, Simulidae, Tabanidae	11	16	351
	43	Nemouridae, Apataniidae, Glossosomatidae, Hydropsychidae, Baetidae, Gyrinidae, Dytiscidae, Tabanidae, Chironomidae	9	12	1 857
	44	Limnephilidae, Apataniidae, Hydropsychidae, Lepidostomatidae, Baetidae, Chironomidae	6	7	172
Alxa left banner	45	Nemouridae, Limnephilidae, Hydropsychidae, Baetidae, Chironomidae	5	8	281
	46	Baetidae	1	1	1
	47	Baetidae	1	1	1
	48	Baetidae, Corixidae	2	2	6
	49	Corixidae, Chironomidae	2	2	40
	50	Caenidae	1	1	2
	51	Corixidae	1	1	4
	52	Dytiscidae, Hydrophilidae, Chironomidae	3	5	87

Information of localities 1 – 52 see Table 1.

Nine Ephemeropteran families from 37 localities were collected. Baetidae was found from 33 localities, Heptageniidae from 17 localities, both Ameletidae and Ephemerellidae from 16 localities, Caenidae from 9 localities, both Leptophlebiidae and Siphlonuridae from 8 localities, Metretopodidae from 5 localities, and Neoephemeridae from 4 localities (Table 4).

Of all the collection sites, the Taoer River of Bailang Town in Hinggan League has the highest number of aquatic insect families (19 families), closely followed by the Budong River in Xinggan League and the Hui River in Hulunber (both 15 families), and then the Monitoring Station of Hanma National Reserve in Hulunber (14 families), the upstream regions of Halaha River of Arxan city in

Hinggan League (12 families), the Huoshaopo of Helan Mountain in Alxa Left Banner (11 families), and the Wuliquan of Arxan city in Hinggan League (10 families).

The locality with the highest species number of aquatic insects is inconsistent with that of the highest family richness, however, the Hui River in Hulunber comes the first with 36 species, followed by the Budong River of Arxan city in Hinggan League and the Taoer River of Bailang Town in Hinggan League (both 30 species), and then the Monitoring station of Hanma National Reserve in Hulunber the third (23 species).

The Simpson index, the Shannon-Wiener index and evenness (Pielou index) were calculated and presented as in Fig. 1. The first three localities with the highest Simpson index values are the Sanchakou of Daqinggou in Tongliao, the Monitoring Station of Hanma National Reserve in Hulunber, and the Ecological Station of Saihanwula National Reserve in Chifeng. The sequence of the first three localities exhibiting the highest Shannon-Wiener index values slightly differs from that displaying the highest Simpson index values, the first locality is the Monitoring Station of Hanma National Reserve in Hulunber, the second is the Sanchakou of Daqinggou in Tongliao, and the third is the Taoer River of Bailang Town in Hinggan League.

Localities with evenness values in descending order are as follows: the Ecological Station of Saihanwula National Reserve in Chifeng, 0.9246; the Sanchakou of Daqinggou in Tongliao, 0.8745; the Monitoring Station of Hanma National Reserve in Hulunber, 0.7975; the Taoer River of Bailang Town in Hinggan League, 0.6178; the Hui River in Hulunber, 0.6178; the Budong River of Arxan city in Hinggan League, 0.4260.

By comparing these localities with the highest diversity values of above-mentioned 4 indices, we concluded that the diversity of aquatic insects in the eastern Inner Mongolia is richer than that in the western Inner Mongolia. In the eastern Inner Mongolia, the diversity in descending order is Hulunber, Hinggan League, Tongliao and Chifeng.

3.2 Evaluation of water quality by the diversity of aquatic insects

The results of the evaluation of water quality by family biotic index, EPT species richness and Shannon-Wiener biodiversity index are shown in Table 5.

Table 5 shows that the number of localities divided into different levels of water quality evaluation are as follows: *FBI*: excellent 15, very good 12, good 3, fair 3, fairly poor 2, poor 1; EPT: very good 27, good 4, fair 5; Shannon-Wiener: good 1, fairly poor 29, very poor 6. Based on different drainages, the result of water quality evaluation of different rivers is as follows: Localities 1-4 belong to Gen River: *FBI*: excellent 3, good 1; EPT: very good 3, fair 1; Shannon-Wiener: Fairly poor 4. Localities 5-11 belong to Halha River: *FBI*: Excellent 1, Good 1, Fair 1, Poor 1; EPT: very good 3, good 1; Shannon-Wiener: fairly poor 4. Locality 12 belongs to the Taoer River: *FBI*: excellent 1; EPT: very good 1; Shannon-Wiener: fairly poor 1. Localities 13-37 belong to the Xar Moron River: *FBI*: excellent 7, very good 10, good 1, fair 1, fairly poor 1; EPT: very good 14, good 3, fair 3; Shannon-Wiener: good 1, fairly poor 14, very poor 5. Localities 38-52 belong to the branches of the Yellow River: *FBI*: excellent 3, very good 2, fair 1, fairly poor 1; EPT: very good 6, fair 1; Shannon-Wiener: fairly poor 6, very poor 1.

By comparing these evaluation results of above-mentioned 3 indices, we found that the evaluation results of *FBI* and EPT were similar, but differed greatly from that of Shannon-Wiener index.

Three kinds of indices (EPT species richness, family biotic index and Shannon-Wiener biodiversity index) also show that water quality of the Agrun River and the Taoer River is much better than the Liao River and the Yellow River.

4 DISCUSSION

As stated before, the evaluation results of *FBI* and EPT were similar, but differed greatly from that of Shannon-Wiener index. The situation is not unique: Bao *et al.* (2010) found that the deviation between the assessments by the Shannon-Wiener biodiversity index and the biotic index in evaluating water quality of Nushan Lake, Anhui province. In analyzing the causes of the situation, Ke *et al.* (1996) noted that, firstly, the Shannon-Wiener biodiversity index ignores the differences of sensibility and tolerance between insect species, and the unevenness of the number of interspecific individuals in a community may decrease the values of Shannon-Wiener biodiversity index, these two factors would influence the evaluation of water quality; secondly, the EPT species richness only involves in the number of species rather than in the number of individuals of each species, that would lead to deviations in the evaluation of water quality; thirdly, the family biotic index considers the tolerance value of the family level and makes up the deficiency of Shannon-Wiener biodiversity index, so

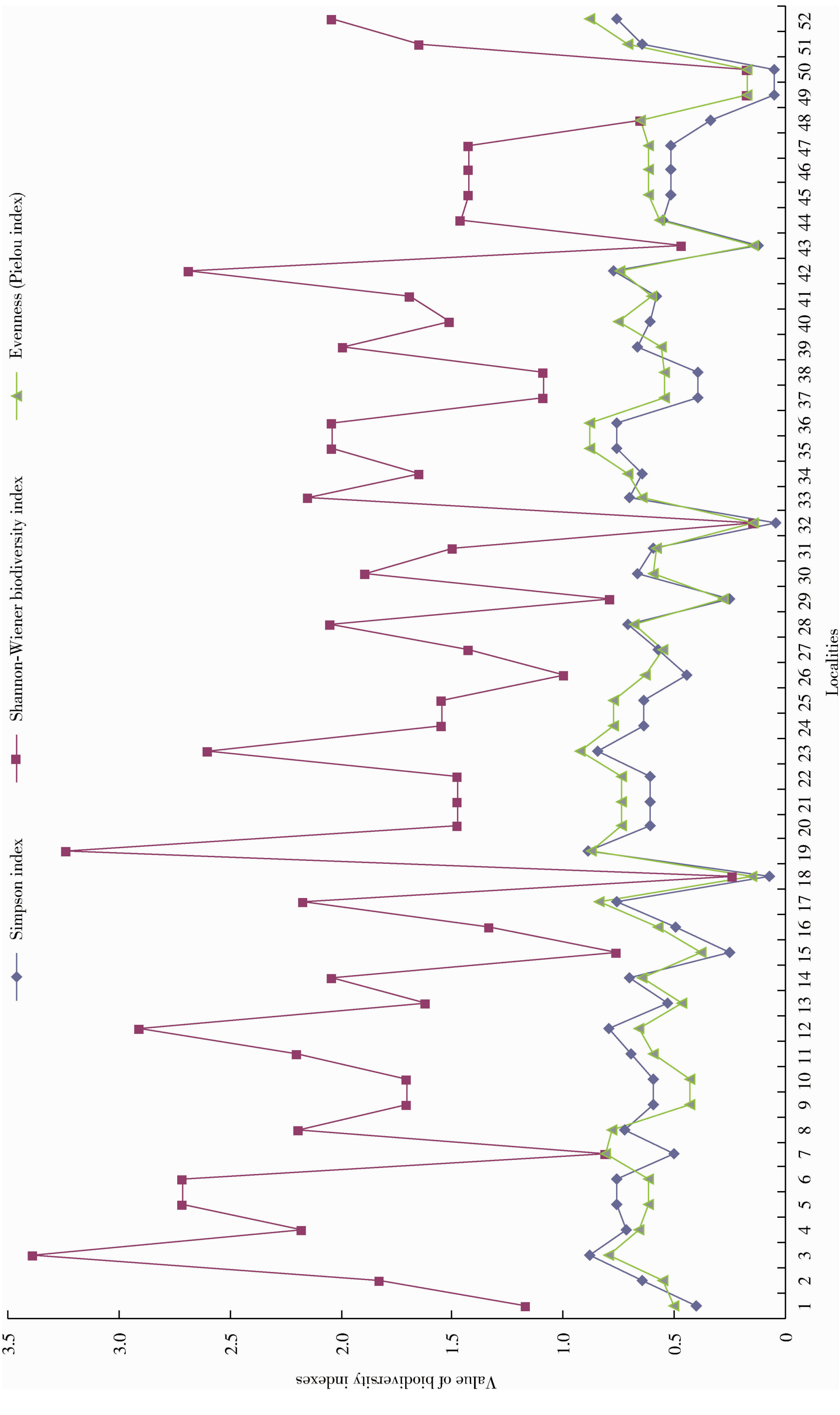

Fig. 1 Analysis of index of biodiversity of 52 localities

Information of localities 1 - 52 see Table 1.

Table 5 Comparison of the evaluation of water quality by three diversity indices

Locality no.	Family biotic index	*FBI* evaluation	EPT species richness	EPT evaluation	Shannon-Wiener biodiversity index	Shannon-Wiener evaluation
1	4.64	Good	6	Fair	1.7899	Fairly poor
2	2.74	Excellent	153	Very good	1.9463	Fairly poor
3	3.37	Excellent	440	Very good	3.1570	Fairly poor
4	3.26	Excellent	410	Very good	2.2146	Fairly poor
5	5.49	Fair	339	Very good	2.6633	Fairly poor
8	6.57	Poor	19	Good	2.1894	Fairly poor
9	3.88	Excellent	2 500	Very good	1.7435	Fairly poor
11	4.91	Good	1 206	Very good	2.1325	Fairly poor
12	2.76	Excellent	934	Very good	2.8786	Fairly poor
13	4.02	Very good	297	Very good	1.5425	Fairly poor
14	3.33	Excellent	93	Very good	1.9372	Fairly poor
15	3.94	Very good	99	Very good	0.6312	Very poor
16	3.22	Excellent	321	Very good	1.3287	Fairly poor
17	3.30	Excellent	77	Very good	2.1708	Fairly poor
18	3.89	Very good	1 106	Very good	0.2391	Very poor
19	4.12	Very good	18	Good	3.1158	Good
20	5.31	Fair	12	Fair	1.4763	Fairly poor
23	3.78	Very good	22	Good	2.5957	Fairly poor
24	3.03	Excellent	158	Very good	1.5441	Fairly poor
26	1.27	Excellent	15	Fair	0.1371	Very poor
27	4.11	Very good	284	Very good	1.4229	Fairly poor
28	3.04	Excellent	858	Very good	2.0449	Fairly poor
29	4.00	Very good	575	Very good	0.7850	Very poor
30	3.91	Very good	798	Very good	1.8675	Fairly poor
31	3.82	Very good	365	Very good	1.4945	Fairly poor
32	4.00	Very good	48	Very good	0.1461	Very poor
33	3.44	Excellent	401	Very good	2.1464	Fairly poor
34	6.42	Fairly poor	16	Good	1.6447	Fairly poor
35	4.33	Good	15	Fair	1.7002	Fairly poor
39	4.22	Very good	225	Very good	2.1724	Fairly poor
40	5.81	Fairly poor	1	Fair	1.5095	Fairly poor
41	3.41	Excellent	220	Very good	1.6881	Fairly poor
42	2.36	Excellent	264	Very good	2.5906	Fairly poor
43	0.85	Excellent	1 815	Very good	0.4687	Very poor
44	5.14	Fair	69	Very good	1.4574	Fairly poor
45	4.19	Very good	230	Very good	1.4239	Fairly poor

Information of localities 1 – 52 see Table 1. The species of orders Ephemeroptera, Plecoptera and Trichoptera were not found in localities 6 – 7, 10, 21 – 22, 25, 36 – 38 and 46 – 52.

the feedback of the evaluation of water quality is in conformity with geographical environment and conditions in each locality. However, in the field survey we failed to find any specimens of Ephemeroptera, Plecoptera and Trichoptera from 16 out of 52 localities in Inner Mongolia, so we think that EPT species richness is not a suitable assessment method in this area. In conclusion, family biotic index is more adaptable to the water quality bio-assessment of the rivers, streams and lakes due to its accuracy and rationality in Inner Mongolia.

We would keep monitoring the population dynamics of freshwater insects and evaluating water quality by biodiversity indices in the future. Based on our current work, we suggest the species groups of the caddisflies and mayflies that could be used in water monitoring in Inner Mongolia in the future, and propose the following feasible frame about utilization of aquatic insects for monitoring the water quality:

(1) To build a network database to include all

aquatic insect species from Inner Mongolia, especially those of Ephemeroptera, Trichoptera and Plecoptera collected in the past two years.

(2) To continue collecting insects of the above-mentioned three orders in May, June, July, August and September by Malaise trap over the river or lake in the next five years, and then appending those species data to the network database.

(3) To build a collaborated expert group, in order to make sure the specimens being accurately identified.

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内蒙古淡水昆虫物种多样性初步调查

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摘要：【目的】探讨内蒙古水生昆虫的物种多样性，积累基本数据，为将其应用于水质监测奠定理论基础，并为加强保护淡水昆虫资源提供依据。【方法】采用综合定性采样法进行采集，水质评价采用科级生物指数（*FBI*）、EPT 物种丰富度、Shannon-Wiener 生物多样性指数。【结果】在 52 个采集点获取水生昆虫共计 7 目 59 科 187 种。研究发现 1 新种，1 中国新纪录属，2 中国新纪录种，2 内蒙古新纪录科，3 新纪录属，25 新纪录种，另有待鉴种 56 个。7 目昆虫的多样性分析结果显示，毛翅目和蜉蝣目的物种多样性较高，而襀翅目物种多样性明显较低；毛翅目和蜉蝣目的科数和个体数占总类群的 42.37% 和 84.29%，这 2 个目均属优势类群。物种多样性较高的地区主要集中在内蒙古东部，包括呼伦贝尔市、兴安盟、通辽市、赤峰市。通过科级生物指数、EPT 丰富度和 Shannon-Wiener 生物多样性指数的水质评价比较结果显示，前两者的评估结果相近，且明显不同于 Shannon-Wiener 生物多样性指数。【结论】内蒙古地区毛翅目和蜉蝣目昆虫耐污值较低的种类比较丰富，因此，这两类昆虫更适合指示该地区的水质状况。

关键词：毛翅目；襀翅目；蜉蝣目；水质；淡水；物种多样性

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